IN-55
92872
P.48

NASA TECHNICAL TRANSLATION NASA TT-20060

EXTRATERRESTRIAL CIVILIZATIONS: PROBLEMS OF THEIR EVOLUTION

L. V. Leskov

Translation of "Kosmicheskiye tsivilizatsii: problemy evolyutsii, IN: Novoye v zhizni, nauke, tekhnike, Seriya: Kosmonavtika, astronomiya, No.8, 1985, "Znaniye" Press, Moscow, pp.1-55.

THIS COPYRIGHTED SOVIET WORK IS REPRODUCED AND SOLD BY NTIS UNDER LICENSE FROM VAAP. THE SOVIET COPYRIGHT AGENCY NO FURTHER COPYING IS PERMITTED WITHOUT PERMISSION FROM VAAP.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 AUGUST 1987

N87-27410

(NASA-TT-20060) EXTRATERRESTRIAL CIVILIZATIONS: PROBLEMS OF THEIR EVOLUTION (NASA) 48 p Avail: NTIS HC A03/MF A01 CSCL 06C

Unclas G5/55 0092872

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TT-20060		

4. Title and Subtitle	5. Report Date
EXTRATERRESTRIAL CIVILIZATIONS: PROBLEMS OF EVOLUTION	August 1987
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No
L. V. Leskov	
	10. Work Unit No.
	11. Contract or Grant No. NASW-4006

9. Performing Organization Name and Address	13. Type of Report and Period Covered
The Corporate Word, inc. 3 Gateway Ctr., 18 S. Pittsburgh, PA 15222	Translation

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
National Aeronautics and Space Administration Washington, DC 20546	

15. Supplementary Notes

Translation of "Kosmicheskiye tsivilizatsii: problemy evolyutsii, IN: Novoye v zhizni, nauke, tekhnike, Seriya: Kosmonavtika, astronomiya, No. 8, 1985, "Znaniye" Press, Moscow, pp. 1-55.

16. Abstract

The problem of finding extraterrestrial civilizations and establishing contact with them is directly related to the problem of their evolution. This brochure tells about possible patterns in this evolution and the stages in the evolution of extraterrestrial civilizations.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	This copyrighted Soviet work is reproduced and sold by NTIS under license from VAAP, the Soviet copyright agency. No further copying is permitted without permission from VAAP.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	48	

NASA-HQ

CONTENTS

Foreword..... 4

Introduction..... 8

Characteristic Features of the Evolution of Cosmic Civilizations.....10

Technological Evolution.....13

Stochastic Models of Evolution.....28

Heteronomous Evolution.. 34

Intelligence and the Universe.....42

References.....48

FOREWORD

The problem of the plurality of extraterrestrial civilizations has aroused increasing interest over the past decades. /3* The importance of research in this area is emphasized by scientists in every field: physical scientists (astronomers, physicists, chemists, biologists, and anthropologists), social scientists (philosophers, sociologists, historians, linguists), and technical scientists (radiophysicists, technological cyberneticists).

Several reasons for the heightened interest in this field can be cited. The problem of the existence of extraterrestrial civilizations and the possibility of establishing contact with them is one of momentous import. The consideration of such problems helps us to understand our place in the evolution of the Universe and to reveal the profound and diverse aspects of the unity of man and his environment. This is even more important because the Universe is becoming the sphere not simply of human habitation, but, with the beginning of our attempts to conquer space, it is in fact becoming an area of productive activity of our civilization.

The search for extraterrestrial civilizations is also of practical significance. As was noted in Resolution I of the Soviet-American Conference on this problem held at Byurakan in 1971, solving this problem may be of extraordinary importance for the further development of humanity. "If extraterrestrial civilizations are ever discovered, this will have an enormous influence on the scientific and technological potential of humanity, and it could also have a beneficial effect on the future of humanity. Establishing contact with an extraterrestrial civilization will have such practical and /4 philosophical significance for all humanity that attempts to establish such contact warrant substantial effort. The consequences of such a discovery could lead to a significant expansion of human knowledge."[1]

In particular, as noted by Academician V. A. Ambartsumyan, the discovery of the first extraterrestrial civilization would have practical consequences at least equal in magnitude to those of the launching of the first man-made satellite or the production of the first nuclear reaction.

It turns out, however, as strange as it may seem, that we can already talk about the practical significance of the problem

---

[1] The Problem of CETI (Communication with Extraterrestrial Civilizations [Problema CETI (svyaz' s vnezemnymi tsivilizatsiyami)], Moscow, 1975, p. 320.

*Numbers in the margin indicate pagination in the foreign text.

of contact with an extraterrestrial civilization. This is because studies in this area have a direct bearing on our own civilization. For example, in calculating the number of extraterrestrial civilizations capable of establishing contact with us, the similarity or even identity of their paths of technological development with what is characteristic of civilization here on Earth has been assumed. At times the stronger assumption is made, either explicitly or implicitly, that all extraterrestrial civilizations are anthropomorphic. And no matter how close to the truth such hypotheses eventually prove to be, they do allow us to obtain, at our present level of understanding, some quantitative estimates, even if these are neccessarily approximate and somewhat arbitrary in nature.

The technological development of cosmic civilizations is also modeled by extrapolating contemporary and possible future trends evident in the development of our own technology. This aspect of the problem of extraterrestrial civilizations is especially closely related to the most urgent problems of contemporary life, primarily the global problems facing humanity. In particular, a number of parameters characterizing the development of our civilization are now growing at an exponential rate (as a function of time). This growth can hardly continue without limit.

According to theories currently being proposed abroad, the /5
technological development of human society must assume a different, static, nature in the future. The set of parameters determining the level of technological development will remain constant over time. In connection with the the problem of extraterrestrial civilizations, such ideas have been put forward by the American professor G. Stant, who also thinks that in the future the tendency toward "accommodation" with nature rather than control over it will predominate. In some cases, similar ideas verge on predicting a halt to the technological development of society in the future.

The suggestion that conquering space and its resources will help to lessen the acuteness of the difficulties facing a society experiencing continual technological development (probably at something other than an exponential rate) seems quite reasonable, however. It should be pointed out, by the way, that in speaking about conquering space, which defines many of the characteristic features of the contemporary scientific-technological revolution, the term "space-oriented" is often used. But in so doing, sight is sometimes lost of the fact that this is but one of the directions in a two-way process, the other direction being the "humanization" of space and its incorporation into the sphere of the conceptual as well as the practical, including productive, activity of humanity.

In connection with the problem of extraterrestrial civilizations, the question is often raised of the temporal boundaries of the era of the technological development of

society. Some scientists, including the American astrophysicist S. von Horner, think that this period is very short, on the order of tens or hundreds of millenia, or perhaps even only a few million years, and ends with the inevitable "suicide" of society. More likely, however, is a different view: that the technological development of society is limited only by cosmogonic and cosmological factors, i.e., it may continue for billions of years or longer. We should also mention that in his day K. E. Tsiolkovskiy advanced the idea of the possible immortality of human society. He thought that a change in the conditions of life for one civilization or the exhaustion of resources needed for its technological development would lead to resettlement in another part of the Universe where such conditions and resources were available. Mutual assistance would be provided by the different cosmic civilizations to each other. /6

Of course, any of the views enumerated above is not so much a final solution of the problem as it is a possible projection into the future of our present-day beliefs about the possibilities for the development of humanity. But obviously, even in the (almost incredible) event that all the searching for extraterrestrial civilizations proves to be unsuccessful, constructing systematic models of their evolution would still be most useful from a practical standpoint. So it is not surprising that this field of study is increasingly attracting the attention of many serious scholars.

The author of this pamphlet is one of the leading specialists in this country on using the extrapolation method to study theoretically conceivable laws and paths of development of cosmic civilizations. Numerous discussions of his results, for example at the 1981 All-Union Symposium on Extraterrestrial Civilizations in Tallin, and at the annual lectures dealing with the scientific legacy and the further development of the ideas of K.E. Tsiolkovskiy, have served to verify their worth.

The problems dealt with in this pamphlet are considered in terms of what is known as a functional definition of a cosmic civilization. Such a civilization is regarded as a dynamically stable, self-regulating system whose primary distinguishing characteristic is an "active, creative effort to transform its environment." The result of this activity is to simultaneously increase both the stability of the whole system and its structural complexity.

This definition is of course highly abstract; it is, however, quite appropriate for modeling the aspects of the developemnt of cosmic civilizations considered in this pamphlet. Such functional models are able to reflect only some of the features of the processes being dealt with, primarily those related to the development of science and technology, and make no claims to be detailed, adequate representations of social processes. A characteristic feature of this pamphlet is

that the author takes an approach to the problem of extraterrestrial approach to the problem of extraterrestrial civilizations that combines, to the extent possible, considerations of the social, ethical, and philosophical aspects. /7

Using the functional approach, possible scenarios of the future of civilization on Earth are constructed. It is fair to assume that these have a great deal in common. In other words, the devlopment of extraterrestrial civilizations obeys the same universal laws, even though the conditions under which they arise and their original structures may differ considerably. With this as a basis, models for different scenarios for the development of extraterrestrial civilizations are elaborated, and estimates of the probability of any given scenario can even be made. Of course, and this must be emphasized, such models are not complete and are not fully worked out. There is no doubt, however, of their usefulness for refining research programs on extraterrestrial civilizations at the present stage. In any case, the basic predictions made in this pamphlet are, although to a certain degree hypothetical, extremely interesting.

The author shows the difficulties encountered in investigating the development of extraterrestrial civilizations using models based on the assumption of the unlimited quantitative growth of the parameters characterizing these civilizations, notably the consumption of energy and material resources. It is convincingly demonstrated that such growth is possible only within set limits. The essence of the processes involved in the development of extraterrestrial civilizations consists in "successive changes of a qualitative nature, in the harnessing of increasingly complex energy sources and the corresponding material resources." The successive change of technologies, one of the most essential characteristics of these processes, as noted here, "must be the dialectical overcoming of the contradictions arising at each successive stage of the evolution of the extraterrestrial civilizations." /8

The concepts on which the models set forth in this pamphlet are based also allow us to draw conclusions about the prospects for our own civilization in the distant future, a subject of considerable interest. As the author correctly emphasizes, the future of our own civilization and that of extraterrestrial civilizations as well involves rebuilding society on a communist foundation.

It is confidently believed that this pamphlet, so full of absorbing ideas, will be read with profit by all who follow publications dealing with progress in science and technology as well as in society, in particular by the readers of the series Cosmology, Astronomy.

V.V. Kazyutinskiy
Candidate of Philosophical Sciences

EXTRATERRESTRIAL CIVILIZATIONS: PROBLEMS OF THEIR EVOLUTION

L. V. Leskov
Doctor of Physical and Mathematical Sciences

"How queer everything is today!...I wonder if I've changed in the night? Let me think: was I the same when I got up this morning? I almost think I can remember feeling a little different. But if I'm not the same, the next question is, 'Who in the world am I?'

-- Lewis Carroll, Alice in Wonderland

/9

INTRODUCTION

I was discussing an earlier version of this pamphlet with a noted scientist once.

"Flying saucers!" he declared categorically.

"That's insulting," I protested. "I'm writing about something entirely different."

"Space stations in the void!" he continued. "How can you write about something that doesn't even exist?!"

I just wasn't able to make him understand: he was well immunized against the subject of this pamphlet. I am not offended, because I understand. The problem is the cheap sensationalism that sometimes accompanies the serious scientific problem of the search for extraterrestrial intelligence and that triggers the immune response in some scientists.

In fact, this problem, the search for extraterrestrial intelligence, or SETI, as it is sometimes called, warrants the most serious attention on several counts. First of all, the discovery of our cosmic brothers in intelligence would play a uniquely important role in shaping our view of the world: the outcome of the search will determine our ideas about the role and place of intelligent life in the Universe.

Second, there is the possibility of acquiring new scientific information, both theoretical and practical. Third, research into such a complex and complicated problem will require solving a number of theoretical and experimental

problems, and this new knowledge will doubtless find application in solving a wide range of contemporary problems. Fourth, and last, research in this area, regardless of whether the search is successful or not, will enable us to form a clearer picture about the outlook for the future development of our own civilization, about the potential dangers threatening our future, and about the best means of overcoming them. /10

This last point needs to be treated individually. Since the time of the first satellite launching and the first manned spaceflight, mankind has made great strides toward understanding and conquering outer space. There is therefore every reason to consider our own civilization a "cosmic civilization." It is thus even more important to discover the other birthplaces of intelligent life in the Universe, the extraterrestrial civilizations. This is a problem of fundamental importance for astronautics and for astronomy.

Research on discovering other cosmic civilizations is underway now in the USSR, the USA, and other countries. Three ideas played a major role in developing research to its present level. First was the formula proposed by Frank Drake for estimating the number of star systems having planets on which intelligent life might exist. Second was the suggestion made by G. Cocconi and P. Morrison to consider the reception and transmission of radio signals as the most convenient means of establishing contact with civilizations separated by cosmic distances and to use the frequency of the neutral hydrogen line at 21 cm. It was later claimed that searching in the millimeter band would be just as promising. Thirdly, there was the hypothesis of N. S. Kardashev, Corresponding Member of the USSR Academy of Sciences, that the energy consumption of advanced extraterrestrial civilizations might exceed that of ours by several orders of magnitude, so that they would be able to construct radiobeacons of the necessary power.

These ideas provided the basis for the current radio-astronomical approach to the search for intelligent life in the Universe. A major program with the purpose of searching for radio signals has been underway in the Soviet Union and abroad for the past quarter century. However, the search for radio signals, as well as for any other sign of stellar engineering activity by extraterrestrial civilizations, has so far produced no results. Any other civilizations are maintaining a stubborn silence. /11

The failure of the searches can be explained in different ways. According to I. S. Shklovskiy, Corresponding Member of the USSR Academy of Sciences, it is because we are alone in the Universe. Others think that our failure is due to the fact that research is still at the initial stage, and that establishing contact with our brothers in intelligence is only a matter of time. But another point of view is also possible. Corresponding Member of the USSR Academy of Science V. S.

Troitskiy recently analyzed the power required for signal transmissions over interstellar distances using radiobeacons. According to his figures, in order to transmit signals over distances of up to hundreds of light years an omnidirectional radiobeacon would require an amount of energy five orders of magnitude greater than is produced worldwide in one year, and the time required to construct such a beacon would be at least 30 million years. And all this just to inform one's nearest neighbors of one's existence.

It should be emphasized that what we are discussing is the search for other civilizations whose existence can be detected from some kind of evidence of their engineering activity directed at transforming their environment for their own advantage. Such a formulation of the problem reflects its materialistic conception and differs fundamentally from efforts undertaken at one time to search the Universe for an intelligence understood as the free creative force of a spirit that was not necessarily subject to the operation of universal laws. Such an approach is unacceptable, since it is essentially idealistic in nature.

In planning further research on the problem of searching for intelligent life in the Universe, a major role must therefore be played by the refining of scientific concepts concerning the patterns and stages of the evolution of cosmic civilizations, and about the possible directions and rates of their development. It is to a discussion of these problems in the evolution of cosmic civilizations that this pamphlet is devoted.

CHARACTERISTIC FEATURES OF THE EVOLUTION OF COSMIC CIVILIZATIONS

WHAT IS A COSMIC CIVILIZATION? Modern views of life are based on the principle of the development of living nature. The specific form the manifestation of this principle takes in biology is the idea of adaptation. In generalizing this idea, Engels pointed out the dialectical relationship between the laws of development and the functioning of living systems and provided a functional definition of life as the dynamic exchange of substances with the environment. Soviet scientist V. I. Vernadskiy later formulated the idea of the noosphere as a qualitatively new, higher state of the biosphere, the distinguishing characteristic of which is the presence of intelligence. According to the ideas of V. I. Vernadskiy, the basic function of the noosphere is to increase the "cultural biogeochemical energy" available for transforming the surrounding world in the interests of humanity. /12

In fulfilling this function, humanity will first attain a planetary scale in its creative, transforming activity, and then will transcend it. A civilization that has reached the cosmic scale in terms of the quantitative characteristics of its

activity should logically be called a cosmic civilization. A clear example of such activity is the radiation of the Earth in the radio frequency band, which as a consequence of the functioning of radio and television systems at the present time far exceeds that of any other planet in the Solar System in intensity.

Such a functional definition of a cosmic civilization is suitable for any form of organized life. It is also clear that it is valid even if our civilization proves to be the only one in the Galaxy.

Creation and transformation thus constitute the fundamental activities of a cosmic civilization. The fundamental law of the evolution of a cosmic civilization can thus be formulated as follows: the purpose of the intelligent activity of a cosmic civilization is to study, harness, and transform natural forces, to create new ecological niches, and to increase the stability of its own existence

However, in the course of transforming its environment the cosmic civilization cannot itself remain unchanged. Subject to the general laws of evolution of living systems, intelligent life itself must inevitably develop. The counter-entropic evolution of the noosphere is primarily social and technological in nature and finds practical expression in the increasingly complex and differentiated internal structure of the civilization. This constitutes the second law of the evolution of cosmic civilizations. /13

The practical means used for transforming and restructuring the environment is technology. A precondition for successfully utilizing a fairly complex technology is the social division of labor. Therefore, the successive changes in technologies that constitute the actual content of the process of evolution are the dialectical solutions of the contradictions arising at the successive stages of the evolution of the cosmic civilization.

MODELS OF EVOLUTION. Using the functional definition of a cosmic civilization and the above mentioned regularities of their development, we can now pass on to constructing models of the evolution of cosmic civilizations. These models are necessary for clarifying the basic stages and directions possible in the development of a cosmic civilization.

In constructing models for the evolution of cosmic civilizations several requirements are imposed. First, these models must be based on the most fundamental achievements of contemporary science and the predictions for future development in scientifically promising directions. Second, this prediction must be comprehensive. Third, the reliability of this prediction of the sequential developmental stages of a cosmic civilization can be substantially increased by considering the possibility of different solutions for the same scientific and

technological problems. For example, if it is predicted that a civilization will harness nuclear energy, the reliability of this prediction is much greater if the possibility of achieving this goal by constructing different types of nuclear and thermonuclear reactors is taken into consideration. Fourth, the prediction must be based on a combination of deterministic and stochastic, or probabilistic, approaches.

In cases where the prediction is based on sufficiently complete scientific knowledge, the evolutionary model will be deterministic, i.e., defined. A simple indication that the fundamental scientific concepts are sufficiently complete and accurate is the possibility of using them to construct a technological power supply for the civilization. We shall therefore call evolutionary models based on this approach technological. The distinguishing feature of such models is the possibility they provide of constructing a relatively complete picture of evolution.

Evolutionary models based on scientific hypotheses that have not as yet been directly verified we call stochastic. These models describe the functioning of evolutionary processes that are substantially influenced by random factors, for example, the discovery of new phenomena not taken into consideration by the prediction. The set of stochastic models can be viewed as a probabalistic prediction of the development of cosmic civilizations. /14

There are three major groups of stochastic models:

1. Finalist models, in which the inevitable destruction of civilization due to any of a number of factors is considered.

2. Metascientific evolution and the corresponding models based on the hypothesis that contemporary civilization is far from having been perfected, and that further basic discoveries await us that will lead to a radical restructuring of science and technology.

3. Heteronomous evolution, in other words, the simultaneous development of several cosmic civilizations among which there is a reasonably effective exchange of information.

We shall now consider in greater detail specific models of the development of cosmic civilizations.

TECHNOLOGICAL EVOLUTION

LEVELS OF DEVELOPMENT OF COSMIC CIVILIZATIONS. In 1960, the noted English scientist J. Bernal formulated the basic factors around which long-range scientific investigations are focused: 1) energy sources; 2) computers; 3) biology. The ensuing years produced no additions to this list, which is not surprising, since it is a matter of the most fundamental problems, whose solution in coming years will decide the fate of our own civilization. We shall utilize these three criteria to construct a space of possible states of cosmic civilizations; the successive transitions from one of these states to another is what constitutes the process of technological evolution.

The space of cosmic civilization states, as it is called, is shown in Fig. 1. Along the axes of the coordinate system are laid the levels j of the three criteria which, taken together, define the overall level of development of a civilization. The energy

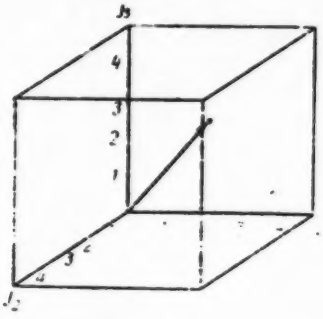

Fig. 1. The state-space of cosmic civilizations. /15

The energy sources (criterion S_1), the systems of information processing and control (S_2), and the auto-organization of intelligent life (S_3) are characterized in terms of these criteria. The higher the level j, the more efficiently energy and material resources are utilized, the greater the stability of the civilization with respect to external effects of various kinds, and the more balanced is the relationship between the civilization and its environment. The number of levels j corresponding to the level of civilization is limited to 4. The first level, with j = 1, corresponds to our civilization here on Earth when we first entered the space age, i.e., approximately 25 years ago.

Two ideas form the basis for the construction of the state-space of cosmic civilizations. The first is the idea of the universality of the physical, chemical, biological, social, and other laws that are valid throughout the entire Universe. Under this assumption, conclusions arrived at by generalizing from the experience and knowledge obtained by our civilization can be universalized. The second idea is that of the general

scientific approach to the analysis of the problems of extraterrestrial intelligence, whose necessity was repeatedly emphasized by A. D. Urcul, V. V. Kazyutinskiy, and others studying the problem.

The distinguishing characteristics of the state-space of cosmic civilizations shown schematically in Fig. 1 are the following. First, these states form a hierarchical sequence of levels. Second, these states are interrelated, and are described by a single system of criteria. Third, in determining each sequential level of development, the possibility of solving scientific and technological problems in different ways is taken into account in hopes of increasing the reliability of the predictions made.

Using the coordinate system shown in Fig. 1, the process of technological evolution can be described by a trajectory in the state-space of cosmic civilizations. We shall examine the most general features of the consecutive stages of the development of cosmic civilizations. /16

STAGES OF EVOLUTION. Level 1. According to criterion S_1, the first, initial level of evolution corresponds approximately to the state of terrestrial civilization when natural heat sources such as oil, gas, and coal are used as the primary sources of power. Worldwide energy consumption at the present time amounts to approximately 250 EJ per year (1 ekajoule = 1 EJ = 10^{18} J), and by the year 2020 it is projected to reach (1-2) x 10^3 EJ per year [1]. However, even this rate of growth provides for a per capita energy consumption only a fourth of that of the developed world today.

On the other hand, the fraction of the Sun's energy scattered by the Earth's atmosphere amounts to 2 x 10^5 EJ per year, which is only 2 orders of magnitude greater than the energy consumption predicted for the year 2020. Growth in energy production beyond this level may lead to irreversible changes in the planet's climate, and is therefore impermissible.

Furthermore, the planetary reserves of such traditional sources as oil, for example, represent the equivalent of only 7 x 10^3 EJ, and the reserves of coal are only a few times greater [1]. All of these concerns make the transition from the first to the second level of evolution in terms of the first criterion a matter of the greatest urgency.

Level 2. At this level of development, nuclear and thermonuclear energy begin to play the major role, and coal, organic wastes, oil shales, etc., are processed into synthetic fuels for vehicles. This will substantially expand the energy potential of our civilization. The worldwide resources of known uranium reserves are equivalent to 5 x 10^4 EJ, and those of oil shales, 10^4 EJ. The known sources of the lithium used as a source of tritium in deuterium-tritium thermonuclear reactors /17

are equivalent to 3 x 10^8 EJ. Once we have harnessed the deuterium-deuterium process, the Pacific Ocean will become a practically inexhaustible primary energy source.

The development of hydrogen-based power supplies will contribute to substantially simplifying our energy problems. It has been suggested that the best possible fuel, pure hydrogen, can be obtained at nuclear and thermonuclear electric-power plants, as well as by using the energy of the Sun's radiation via hydrolysis or thermally catalyzed reactions.

A major contribution to the planet's energy system can be made by a network of electrical space stations in geostationary orbit that convert the energy of solar radiation and then transmit it to Earth for use by industry in the form of highly focused rays in the UHF or laser frequency range. Another direction being explored is the transfer to space of highly advanced technological processes, or those harmful to the environment. The manufacture of new materials in orbiting factories will develop into a profitable sector of the space industry.

The most characteristic features of Level 2 civilizations in terms of criterion S_2, the information and control system, are the rapid growth in the sources of information transmitted between artificial Earth satellites, the development of new types of services, such as teleconferencing, 3-dimensional color television with direct transmission to private receivers, and the wide-scale use of television in education, medicine, and other areas.

Further improvements in computers will lead to the creation of multiple information libraries, and eventually, a global data bank of scientific and technical information. Computer-assisted design will be widely employed, as will switching by means of space communication facilities in a single computer system. All of this will make it possible to dramatically increase the efficiency of scientific research.

In addition to solving the technical problems involved in designing the computers of the next few generations, the development of systems of fundamentally new programs and eventually of heuristic programming, is also required if automatic control systems and computer design are to continue to expand and improve in effectiveness. As defined by the noted Hungarian mathematician G. Polya, the purpose of heuristics is to study the methods and rules for making discoveries and inventions. Heuristic programming is aimed at developing methods for solving the problems of creativity. At this stage, it is logical to speak of artificial intelligence, or AI. /18

There are different ways to approach this problem. For example, in the view of N. N. Moise'ev, artificial intelligence is the totality of the electronic-computational means and

mathematical techniques that provide the best means of attaining a certain specific goal. The selection of the goal and criteria remains the exclusive prerogative of human beings, and the significance of artificial intelligence is that it improves the efficiency of the human mind. According to N. Wiener, the meaning of artificial intelligence is considerably broader.

The fundamental task of civilization in terms of the S_3 criterion (the auto-organization of intelligent life) at level 2 is to dramatically improve living conditions without altering the human biological organization, thus essentially eliminating such inherited and acquired pathologies as cardiovascular disease, cancer, metabolic diseases, mental illness, and so on. Dealing with these tasks will become possible thanks to further advances in molecular biology, genetics, biochemistry, and biophysics, which should lead to a new qualitative leap, the development of a general, theoretical biology.

Theoretical biology will serve as the scientific foundation for further progress in another important direction as well, namely, solving the problem of the food resources of the planet. One promising approach to this problem is to utilize genetic selection. Even at the present time, significant progress is being made in this area. New strains of wheat, corn, beets, and other crops having a valuable genetic endowment /19
have been introduced. Industrial production using microorganisms to manufacture proteins, vitamins, antibiotics, and other substances necessary for the national economy and public health will play a major role in solving the food problem. Petroleum products could serve as the raw materials for such industries.

At level 2, advances in theoretical biology will lead to the solution of still another fundamental problem, the development of a theory of the brain. This is a highly complex task, and solving it will open the way to the practical mobilization of the resources of the human brain. We shall present one example. The ordinary capacity of the human brain does not exceed 10^{15} bits, but its potential capacity, according to calculations made by the cyberneticist John Neuman, is 10^{20} bits. Discovering a way to utilize these resources, to intensify the creative abilities of the human being, will significantly improve the efficiency with which the problems facing mankind can be solved.

In analyzing the problems it will be possible to solve at level 2, it is essential to note one general feature: the final solution of the problems outlined will become possible only under the proper social conditions, which presupposes the elimination of antagonistic class relations.

Level 3. The fundamental characteristic of this stage is the transfer of the major part of industry to continuous operation, the complete utilization of secondary resources, a

sharp reduction in the amount of energy migrating within the system, and the development of ecologically balanced technological processes. At this stage, the environment and the civilization must be optimally adapted to each other. This task was noted in his own day by Academician V. I. Vernadskiy.

It should not be thought that the time for solving the problems of the third stage, the creation of an ecologically balanced energy supply, will arrive only after a civilization leaves level 2. The differences between the second and third stages are chiefly a matter of where the center of gravity will lie in efforts to solve the problems of energy supplies.

At this stage of its development, a civilization will have available to it integrated energy-production and agro-energy cycles that will provide for a well balanced ecological equilibrium between it and the environment. This includes, for instance, chemical bioenergetics and its goal of separating water into hydrogen and oxygen using solar power. The fermentation systems of some bacteria are known to be capable of splitting water, but the efficiency of the process is low. Harnessing this reaction will open up the way to sharply increasing the productivity of agricultural products -- up to 150 tons of dry matter per hectare, i. e. more than 10 times the current level, and at the same time it will provide large quantities of free hydrogen This method, calculated N. N. Semenov [2], can provide up to 50 watts per square meter of energy. /20

In industry at this stage, technological processes are developed that are based on the harmonizing, the bringing into phase, of energy production cycles. As a specific example of this kind of process, consider the possibility of using chemical reactions with the selected excitation of the necessary energy levels of the atoms and molecules.

At the stage $j = 3$, some of the problems considered above will take on still greater significance: artificial intelligence, heuristic programming, advances in computer design. Generalization of the research carried out at the previous level will provide a unified theory of self-organizing systems, the most important object of which is civilization itself. The distinctive characteristic of the third stage of development of a civilization, in terms of control, is the transition to a purposeful and planned development of the ecological optimum on a planet-wide scale.

The transition to the third level in terms of the criterion S_3 is characterized by the solution of fundamental, interrelated problems: the regulation of the genetic code for specific purposes, and bioelectronic cybernetic systems. The first of these areas, genetic engineering, or genotechnology, may first be applied to microflora, and only later to the plant and animal kingdoms.

The methods of genetic engineering are already finding application in the selection of microorganisms than can dramatically increase the effectiveness of the microbiological industry. The next stage is the restructuring of the genetic makeup of useful plants. This may include solving problems like producing species of plants able to fix nitrogen, altering the makeup of plant protein to make it more similar to animal protein, developing plants able to split water into hydrogen and oxygen, and so on. This will be the basis for the broad development of bioenergetic and agroindustrial complexes [3]. /21

When we speak of the development of bioelectronic systems it should be noted that these are used primarily to provide artificial human organs. At the present time, efforts to construct artificial hearts, bioelectronic limbs, and organs of vision and hearing are widely known. The theoretical possibility of direct interaction between man and computer allows us to consider the prospect of developing highly effective teaching methods, a dramatic increase in individual creative abilities, using a mode of dialog between the memory of the computer and its programming, etc. The use of terminals and personal computers can make these possibilities widely available.

Undoubtedly the most difficult problem that a civilization is faced with at the level j = 3 is the preservation of the personality. We recall that the dialect of life is that the biosphere is immortal, the individual mortal. However, the personality per se is a dynamic category. Accordingly, the problem of safeguarding it must be understood not as the maintenance for some infinitely long period of some steady state, even such a pleasant state as eternal youth, but as support of the continuous development of the personality. It is important here to ensure the personality the right to freely choose this continuity

Level 4. The fourth, highest level of technological evolution is associated with the distant prospects for harnessing such energy sources as the mutual annihilation of matter and antimatter, superdense states of matter, superheavy atomic nuclei, muon and quark catalysis, etc. We shall combine all these still hypothetical possibilities under the general term paraenergetics. /22

Each of the possibilities listed is still highly hypothetical, of course, which justifies us in refraining from undertaking any serious analysis of them. But since there are so many fundamentally new hypothetical possibilities, we can consider that the mathematical expectation of solving the problem of paraenergetics by some particular means is substantially greater than zero.

In addition to achieving paraenergy, at level j = 4 we can also expect the tasks of replication to be dealt with, i. e.,

the completely automated, low-energy-intensive production of any type of material object. Another problem will also be solved, one originally set by V. I. Vernadskiy, namely, that of geotechnology, or the synthetic production of mineral resources. To describe these advances in energy supplies and technology at level j = 4 we introduce the term ecoenergetics.

In terms of the control criterion, the fourth and highest level in the development of cosmic civilizations is characterized by a marked improvement in the efficiency of scientific research, due principally to radical changes in the role of the computer. This includes instrumental methods for obtaining qualitatively new information. To summarize these features of scientific research we use the term "cogeneration" Ccgenerative methods of obtaining new information using a computer may be based on the highly advanced electronic technology of the future, the methods of heuristic programming, computer experiments, etc.

The requirements for such a fundamentally new approach to the solution of fundamental problems are already in existence. We cite as an example the USSR State Registry of Discoveries, where under No. 55 is entered the discovery of a new phenomenon, the formation of a high-temperature electrically conductive T-layer within a plasma contained by a magnetic field. This discovery was made by the research group headed by Academicians A. I. Tikhonov and A. A. Samarskiy as a result of computer modeling. /23

Now let us proceed to the description of level 4 in terms of the self-organization of intelligent life. Solving the problem of the preservation and creative enrichment of the personality, of mobilizing the resources of the intellect thrcugh the interaction of man and computer, leads to the question of a qualitatively new stage in the development of intelligent life, the transition to the appearance of a single planetary intelligence. This is undoubtedly the most hypothetical problem in the entire analysis. And all the preconditions necessary for it to be posed are currently in existence.

The establishment of multiple efficient links between man and machine, the group and the machine, man to machine to man, and so forth, will on the one hand ensure the fullest development of the individual's creative potential and its greatest possible self-expression. On the other hand, however, these same processes amount to the diffusion, the vanishing of the boundaries that originally divided one personality from other individuals and from the collective intellect. One consequence of this process is the dramatic intensification of the basic creative and educational functions of civilization. We call this highest form of auto-organization of intelligent life in the given model the "noobios", from the Greek words "noos" (intelligence) and "bios" (life).

The dialectics of the transition to this phase of the existence of intelligence can be thought of as the last level in the discovery of the creative potential of the individual, which will be made possible only by strengthening and multiplying interpersonal ties. The problem of the information explosion and the information crisis is often considered a negative consequence of the revolution even today. The transition of intelligence to the state of the noobiont will ensure the most effective elimination of the undesirable consequences of this crisis and will create the preconditions for the further development of intelligence in the future.

Ideas about the immortality of the mind, and about the inevitability of its transformation into the most powerful force in the Universe were frequently expressed by K. E. Tsiolkovskiy. In his day, however, there were no cybernetics, molecular biology, biochemistry, biophysics, biotechnology, or microelectronics, so that K. E. Tsiolkovskiy could not find an adequate form for his ideas. In our day, such a possibility exists. /24

The successes of modern science have made the promise of genetic improvement a reality. However, in considering this prospect in an analysis of the specific means for cosmic civilizations to move on to the noobiont, we must be careful to avoid any misunderstanding about the meaning of the problem.

It would be a mistake to think that only technological problems stand in the way of reaching this goal. On the contrary, we are talking about a distant, even hypothetical, prospect. It is important to emphasize in this regard that there is one preliminary condition that must be met if the possibility of raising the collective intellectual potential of the civilization by the transition to the noobiont is not to be turned into its opposite. This condition is that the exploiting classes be eliminated from the face of the Earth.

Only after the victory of Communism on a worldwide scale will the conditions be created for the scientifically based practical formulation of the question of the transition of the civilization to higher evolutionary levels as measured by the criterion of the self-organization of intelligent life. In formulating this problem we must consider it from a number of different standpoints, not only the technological, but the social, ethical, and moral as well.

A summary of the most important distinctive features of the levels of development of cosmic civilizations discussed in this section is given in Table 1.

Not so long ago the Swedish astrophysicist H. Al'ven put forward a utopian version of the "civilization of pleasure" which was based on the fact every person would be connected by special microelectronic and bioelectronic devices, which he

called the neurototal and the minitotal, to a gigantic computer brain. This brain ensures human beings a life filled with standardized pleasures, but at the same time deprives him of any creative initiative.

A similar view has been developed by the American cyberneticist J. McCarthy, according to whom the implantation of a miniature computer in the brain "means a new evolutionary jump in the development of mankind." The South American physiologists J. Delgado has successfully performed experiments of this kind on animals. According to Dr. Delgado, the basic problem now is to decide "what kind of human being it is we want to design." The American geneticist M. Barnet goes even farther and takes as his goal the radical restructuring of the human being as a biological species.

The technological possibilities--the methods of gen·technology, miniature computers and electrodes implanted in the brain for direct connection to a mainframe, biochemical reactions, all exist. For what purposes they are to be used is a different matter. In the West, the creation of a "controllable pyschocivilized society," the introduction of species of "cyborgs" or "parahumans"--races of mutants, obedient in every way to their masters--is often called for. There is no need to explain to the Soviet reader that the fundamental objective of these misanthropic "theories" is to preserve the capitalist system for all time. These are basically the same ideas followed by the rulers of the Nazi Reich, who dreamed of turning the entire world into a gigantic concentration camp, but now dressed up in modern scientific clothing. /25

It is clear enough that such "ideas" are inconsistent with the fundamental laws of the evolution of cosmic civilizations. Between the sociobiological and biocratic ideas of some Western thinkers and the idea of the noobiont there exists a fundamental difference. The basic objective of the "psychocivilization revolution" is the unification of human individuals and the suppression of their creative diversity. The main objective of the transition to the state of the noobiont is exactly the opposite: it is the greatest possible enhancement of the individual creative potential of the personality, the fullest mobilization of his potential in the interests of the civilization. This is why the "controlled psychocivilized society" means reducing the diversity and the creative potential of the socium, while the noobiont means raising these to their highest possible levels. Whether the same arsenal of biological, chemical, and technological means can be used to achieve these diametrically opposite goals is another matter.

It would be a mistake to think that only technological problems stand in the way of reaching this goal. On the contrary, we are talking about a distant, even hypothetical, prospect. It is important to emphasize in this regard that there is one preliminary condition that must be satisfied if the

possibility of raising the collective intellectural potential of the civilization by the transition to the noobiont is not to be turned into its opposite. This condition is that the exploiting classes be eliminated from the face of the Earth.

Only after the worldwide victory of Communism will the conditions be created for the scientifically based practical formulation of the question of the transition of the civilization to higher evolutionary levels as measured by the criterion of the self-organization of intelligent life. In formulating this problem we must consider it from a number of different standpoints, not only the technological, but the social, ethical, and moral as well.

A summary of the most important distinctive features of the levels of development of cosmic civilizations discussed in this section is given in Table 1.

/26

TABLE 1. THE LEVELS OF TECHNOEVOLUTION

	S_1	S_2	S_3
1)	Chemical power sources	Wide use of computers, branch-wide automatic control	Research on genetics, molecular biology, biochemistry, biophysics, medicine, ecology
2)	Nuclear and thermonuclear power, industrialization of space, hydrogen power	Global system of manipulating information and control, heuristic programming, artificial intelligence	Elimination of disease, solution of the problem of food supply, methods for mobilizing the resources of the brain
3)	Biochemical power, energy-producing and agro-industrial complexes, appropriate technology	Computer-designed ecologically optimized biosphere and noosphere	Purposeful control of the genetic code, symbiosis of man and computer
4)	Paraenergetics, replication, geotechnology, ecoenergetics	Phased methods of scientific research, computerized methods for obtaining qualitatively new information	Post-social stage of evolution of cosmic civilization, the noobiont

Perhaps the greatest shortcoming of the state-space of cosmic civilizations described in Table 1 and Fig. 1 is its excessively anthropomorphic character. However, any attempt made in advance to exclude an anthropomorphic approach would make the analysis much less concrete, and would severely limit its predictive content. It should also be pointed out that, as the numerical index of the hierarchical states rises to j = 3 and 4, the indeterminacy of the predictions also rises, and the highest levels appear only dimly through the cloud of our present-day ignorance. However, on the whole the broad outlines of the space of possible states of cosmic civilizations are most likely correct. /27

In considering the progress of technological evolution it is logical to ask a question that is sometimes raised: Is it possible for there to be a "nontechnological" evolution of a cosmic civilization? No, it is not possible, if technology is understood as the sum of all the means the cosmic civilization uses to fulfill its creative adaptational function. It is another question, however, whether technology must always be based on production by machine, as it is at the present stage of development of our civilization here on Earth.

PATTERNS OF TECHNOLOGICAL EVOLUTION. The possible stages, or levels, of the technological evolution (or simply, the technoevolution) of cosmic civilizations were given in Table 1. The transition from the possibility of such a development to its necessity is determined by the laws of technoevolution.

To make the analysis given above more concrete, we formulate the following laws of the general features and driving forces of the evolution of cosmic civilizations.

1. The practical expression of the fundamental creative function of a cosmic civilization is the operation of its technological evolution, which consists in the successive transition among all the higher levels of its development.

2. The technological evolution of a cosmic civilization is accompanied by the increasing complexity of its internal structure, an increase in the flow of information used for optimizing control over its activity, and by the development of a large number of new channels of communication among the structural elements of the civilization.

These laws have a number of important consequences. First, it is possible to assert that the main tendency of technoevolution consists in the transition among qualitatively different states, or in other words, the process is primarily one of intensification. Second, the evolution of cosmic civilizations that arise under different conditions and whose original structures many differ significantly follows the same universal laws. The development of each autonomous cosmic civilization can be represented as a movement along a trajectory in the state-space illustrated in Fig. 1. /28

The third consequence relates to the evolution of a cosmic civilization as a dynamic process. This process is subject to the exponential laws of growth. However, under real conditions it is necessary to take into consideration such factors as the limited nature of natural resources, the possibility of the ecological balance being disturbed due to the productive activity of the civilization, etc. According to these principles, the probabilities of the evolution of cosmic civilizations along different trajectories are different, or in other words, there must exist selection rules for such trajectories.

The fourth consequence results from the second law of technoevolution, and relates to the cybernetic control structure of the cosmic civilization. At particular stages of its evolution, this control structure may cease to correspond to what is required for development. The necessity for dialectically overcoming the contradictions that arise in this case may impart a dramatic cast to the evolution of the cosmic civilization.

We give an example. In the words of Norbert Wiener, the capitalist system is an example of an antihomeostatic control structure. Disturbances that arise within its economic mechanism do not die out in time, and ensuring ecologically balanced growth, an urgent necessity for our civilization, is impossible in principle under the capitalist system of production. Therefore, the unlimited development of civilization under the capitalist system is forbidden.

Let us return to the third consequence. The value of the criterion S that governs the development of a civilization can be considered as an increasing function of the parameter j (Fig. 2). Since the dynamic processes of growth are usually described by exponential laws, this increasing function can be conveniently represented by an expression of the form /29

$$S = S_0 e^{(j2-1)},$$

where S_0 is the initial value of the criterion S (for simplicity we can let S equal 1), and e is the base of the natural logarithms, i. e., e = 2.72.

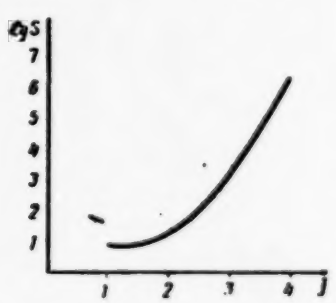

Fig. 2. The S criterion as a function of level number j.

On the other hand, the variable value of S depends on time. In the simplest case, this relationship is also exponential in nature

$$S = S_0 e^{\delta t},$$

where δ is the index of the level, or the increment. Combining these two formulas, we obtain an expression for calculating the time necessary for a civilization to reach the j-th level of development:

$$t = \frac{1}{\delta}(j^2 - 1)$$

The results of numerical calculations made using this formula are shown in Fig. 3. Here curve 1 corresponds to $\delta = 5 \times 10^{-2}$, i.e., approximately the present rate of growth of terrestrial civilization (cf. Table 1). For curve 2, $\delta = 10^{-4}$, which corresponds to a significantly slower rate of development. Curve 3 is computed for the case when the rate of evolution as measured by the rate of development sharply decreases, and curve 4 reflects the case when the increment changes with the transition to each successive level of development. /30

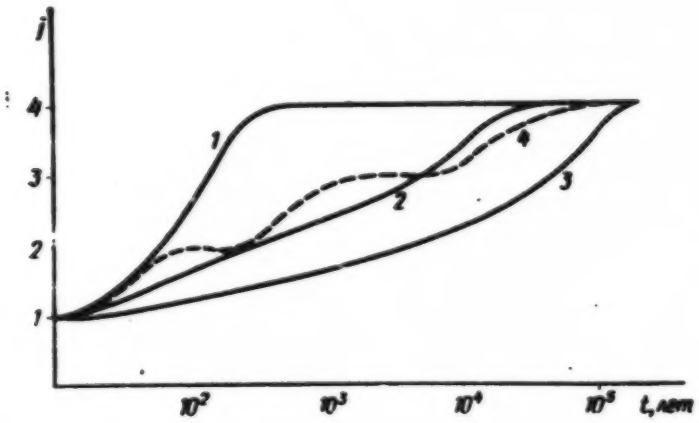

Fig. 3. The dynamics of technological evolution. 1) $\delta = 5 \times 10^{-2}$; 2) $\delta = 10^{-4}$; 3) δ is a decreasing function of j; 4) δ is a variable quantity. Key: 1 - years.

In evaluating the prospects it should be pointed out that a decrease in the rate of intensive development under conditions when pollution of the environment is increasing and the reserves of nonrenewable resources are being depleted may lead to crisis situations.

EXTENSIVE AND INTENSIVE DEVELOPMENT OF COSMIC CIVILIZATIONS. When people talk about the evolution of cosmic

civilizations they frequently have in mind primarily numerical measures, chiefly power consumption. Starting from this principle, N. S. Kardashev suggests considering civilizations of types I, II, and III, which have arrived at a level of energy consumption on the scale of the energy: 1) obtained by the planet from its own sun; 2) radiated by the sun; and 3) radiated by all the stars of the galaxy (3×10^6, 1.3×10^{16}, and 1.3×10^{27} EJ per year, respectively). According to calculations made by I. S. Shklovskiy, at the final stage of this development the rate of growth in energy consumption attains a colossal value, on the order of 10^{21} EJ a year.

This type of evolution of cosmic civilizations, which is described primarily by the growth in its quantitative indicators, is called extensive. The alternative to the extensive development of a cosmic civilization is its intensive evolution, which is characterized primarily by qualitative, not quantitative changes (cf. Table 1). Let us use the third consequence of the laws of technoevolution to assess the relative probabilities of the extensive and intensive evolution of a civilization First we shall analyze the types of difficulties a cosmic civilization will encounter if it adopts a strategy of unlimited expansion in space.

There are at the present time a number of projects for installing in the space around the Earth and the Sun various long-term orbiting vehicles for industrial purposes, space-based solar electric power stations, plants for manufacturing new materials, and space settlements. No doubt, many of these projects will be implemented for the benefit of mankind. As for harnessing a significant part of the Sun's radiant energy, that is a different matter. If humanity remains on the Earth, only an insignificant fraction of this energy, no more than 10^{-10} - 10^{-11} of the total, can be utilized without causing changes in the planet's climate that would have catastrophic consequences for the biosphere. /31

K. E. Tsiolkovskiy demonstrated long ago a means to increase this value by constructing large-scale settlements in space. A detailed analysis of such projects carried out on the basis of modern scientific and technological achievements was recently made by A. T. Ulubekov. He considers the possibility of dismantling existing planets and constructing in their place more convenient replacements, of constructing space cities from the material of planets, etc. All these plans require the transport of significant masses of matter between different circumsolar orbits.

Let us consider as a typical example of such transport operations the dismantling of Io, one of Jupiter's moons, and the construction from its wreckage of space settlements close to the Earth's orbit. It is estimated that the energy requirement for such transport operations is on the order of 10^{30} EJ. If the most promising thermonuclear engines are used for these

transport operations, the amount of thermonuclear fuel required will be about 10^{14} tons. We recall that the total reserves of the lithium in the Earth's oceans used as the fuel in a deuterium-tritium reactor amounts to only 2×10^{11} tons.

Similar estimates allow us to conclude that at this stage of technoevolution, such plans to utilize a larger fraction of the Sun's radiant energy do not appear feasible. Under conditions of limited energy consumption, the intensive path of evolution is more effective. Let us assume, however, that some fraction of the civilizations have overcome these difficulties and have headed for the nearest stars. At this stage there arises a specific new problem, that of maintaining the integrity of the cosmic civilization, whose extent in space is on the order of interstellar distances. Ultimately, such a civilization must necessarily lose its coherence and break down into autonomous, weakly interacting systems. Since this contradicts the fundamental law of the evolution of cosmic civilizations, the selection of a similar type of strategy development is unlikely. /32

There are factors that make the space orientation of human activity unavoidable: the exhaustion of natural resources, the increasing pollution of the environment by industrial wastes, the need for new sources of energy, and the efficiency of industrializing space. The exit to space and reaching a level of energy consumption on the order of, let us say, that of the energy received by the Earth from the Sun, is one thing, and the inevitability of the unlimited growth of energy consumption up to the stellar and galactic scales is another. The necessity of a civilization's developing in this last direction is not a consequence of the laws of its evolution.

The foregoing allows us to draw the following conclusion: the probability of the existence of a cosmic civilization of type II and especially of type III is very small. In fact, the only direction the technological evolution of a cosmic civilization can take is intensive development, based primarily on periodic transitions to new, increasingly efficient technological productive processes, ensuring the maintenance of balance with the environment, and accordingly on the periodic restructuring of the civilization. The growth in the quantitative indices, primarily of energy consumption, occurs only to the extent that these fundamental conditions of evolution are not violated.

And what is the subsequent fate of the cosmic civilizations that have reached the highest stage of development of intelligent life following the path of intensive evolution? The answer to this question cannot be obtained within the framework of the model of technological evolution.

WHAT IS THE PROBABILITY OF THE DESTRUCTION OF A COSMIC CIVILIZATION? And so, the technological flight of civilizations at the cosmic scale lasts no longer than the life of a summer butterfly. And then what? Some researchers, including S. von Horner and F. Dorshofskiy, claim that later, there is nothing. After having experienced their precipitate rise, cosmic civilizations inevitably perish: either by losing their taste for life in the lap of a consumer's paradise, or by suffocating in technological wastes, or finally, by being consumed in the flames of a nuclear catastrophe. The duration of this flight is short, no longer than 10^3 years. According /33
to this view, it is precisely the shortness of the lifetime of a civilization in the technological phase of their development that accounts for the "vacuum of civilizations" in the Universe surrounding us that the SETI researchers have encountered.

We agree that such dangers are doubtless quite real. But more important is another question: how great is the probability that a cosmic civilization during its evolution will find sufficiently effective means to avoid a similar apocalyptic end? To examine this question, let us examine in greater detail what arguments S. von Horner and the others present in favor of their finalistic conceptions.

1. The destruction of a civilization as the result of a cosmic catastrophe of sufficient proportions (a star going supernova, a collision between stars, the exhaustion of the fuel supply of its own sun, etc.). But, first of all, such catastrophes are extremely rare phenomena, and secondly, they develop so slowly that the civilization would most likely have time to adapt to the changing conditions.

Recently the American astrophysicist F. Dyson put forward what he calls a theory of cosmic ecology. This theory is based in particular on the axiom of adequacy, according to which life, given enough time, can adapt to any environment. A similar point of view was defended in his writings by K. E. Tsiolkovskiy, who thought that intelligent beings could live even in the vacuum of outer space, using the energy of the Sun directly to sustain life.

2. The destruction of civilization as a result of global factors (exhaustion of natural resources, energy crisis, pollution of the environment, etc.). The history of humanity provides many examples of the destruction of ancient civilizations due to their own errors. This could be by turning their own country into a desert or destroying its animal life, but each time the true, fundamental reasons behind the ecological catastrophe were social in nature, and were due to the struggle between antagonistic classes. Such dangers exist even today.

The true proportions of such problems are fully understood even by Western scientists. From them proceed alarmist ideas and ideas of a globalism of another sort, which they formulate as recipes for saving humanity by unifying it in a fight against growing crisis phenomena. However, the adherents of this point of view do not take into account the major point, the social roots of the phenomena for which they are seeking a medicine. The true path to overcoming the energy, environmental and other crises and their dangerous consequences for humanity leads through the establishment of a just social system throughout the entire world. /34

3. The danger of social conflicts and of nuclear catastrophe on a worldwide scale. There is no doubt that this is a serious threat.

But there is also no doubt that the forces of peace and progress, at least on the planet called Earth, are filled with determination to remove this danger from the future of their own civilization. And they are capable of doing this.

In speaking of social factors as the sources of a potential threat of global proportions it should also be pointed out that they are dangerous not only in themselves, but as a "trigger" for irreversible changes caused by energy, ecological, demographic, and other crises. Preventing the dangerous consequences of these factors clearly depends first of all on the level of understanding of the problem, the sense of responsibility and good will of the intelligent beings making up the social unit, i.e., the cosmic civilization, who are willing to defend their future.

4. The self-destruction of intelligent life due to intellectual or spiritual degeneracy in a "consumer's paradise." One group of models of this type of dissolution of civilization has been well-studied in Western belles lettres, for example Aldous Huxley's Brave New World. It is clear enough, however, that such models are based on a simple extrapolation of society into the future, and the corresponding exaggeration of real social contradictions of the contemporary capitalist system. It is just as clear that the capitalist system is far from being fatally ensconced by the inevitability of the evolution of cosmic civilizations. /35

Another set of arguments is based on considerations of a technological nature. In the automated "consumer's paradise" promised humanity by the onrush of technology, the acute need for intellectual activity to provide the neccessities of existence will apparently disappear. The lack of necessity will inevitably lead to the snuffing out of the intellect.

This reasoning is seriously flawed. A "consumer's paradise" that grows without bounds is simply a fairy tale that will never come true. On the contrary, the existence of cosmic

civilizations is a process involving the solution of contradictions at each new stage, a process of overcoming new problems that demands from the civilization the permanent mobilization of its entire intellectual potential.

This analysis leads us to conclude that cosmic civilizations are highly stable against disturbing factors of external and internal origin. This of course does not mean that the destruction of a civilization is completely impossible, but the probability of such an outcome is very small. It is important to emphasize in this connection that cosmic civilizations must as a rule find a way out of potentially dangerous crisis situations via intensive development.

THE LIMITS TO THE EVOLUTION OF SCIENCE. Since the possibilities for generalizing modern scientific and technological achievements have been exhausted to a considerable degree by the construction of the model of technological evolution, any subsequent analysis must of necessity be stochastic in nature. The fundamental hypothesis of the corresponding stochastic models for the evolution of cosmic civilization can thus be formulated as follows: contemporary basic science is far from having reached the final stage of perfection, and consequently, the number of possible states of cosmic civilizations j in Table 1 can be taken as greater than $j_0 = 4$.

Let us analyzize the bases for this hypothesis taking physics as an example. According to contemporary ideas, physics is the study of nature dealing with the most general properties of the physical world. As a consequence of this generality, the laws of physics form the foundation of science in general. The basic objective of physical theory is to explain the experimentally observed structure of the physical world. "Our goal," wrote P. Dirac, one of the giants of modern physics, "is to obtain a unified, all-inclusive theory, suitable for describing all of physics...Such an all-inclusive theory has not as yet been constructed. It is the ultimate goal towards which all of physics is striving." /36

Will this goal ever be attained, and will theoretical physics ever be completed?

This is the opinion of Stanley Hawkin, a leading modern theoretical physicist: "It is not impossible that we will see a completed theory during the lifetime of some of those present here today." We recall that in the history of physics similar announcements have been made many times, but new discoveries later forced the theoreticians to admit they had been mistaken. Of course, every time the physicists made such assertions they were supported by serious arguments. However, even in this case one cannot talk about the completion of science in toto. There are still possibilities for science to move to qualitatively new, higher levels of development through systematization of the

knowledge acquired by different scientific disciplines, and through new discoveries at the interface of different scientific trends.

MODELS OF METASCIENTIFIC EVOLUTION. When we talk about the development of science in general, and not just of physics, it is essential to note one common feature of a basic nature: the fundamental objects of investigation are becoming ever more complex phenomena, representing a complicated totality of disparate processes. The predominate role in the investigation is beginning to be played by the systemic approach, leading to a change in the usual reduction of more complex to more simple, elementary, phenomena. At this new stage of its development, science poses and solves the problems of the complete description of complex objects of the material world by constructing a set of models of various degrees of complexity and different structures to form an interrelated hierarchical unity.

The inevitability of science developing in this direction was pointed out by Karl Marx. "History itself," he wrote, "is a real part of the history of nature, the formation of nature by Man. Later, science includes within itself the science of Man to the extent that the science of Man includes within itself natural science: it will be one single science." /37

Some readers may ask: Is it worth hurrying to peer into the wells of still undiscovered scientific truths? Wouldn't it be safer to wait?

The following objection can be made. As it develops, science does not throw off what served as its base at previous levels of development, but only redefines the limits of the applicability of the older theories. Therefore, when talking about essentially new discoveries that likely await us in the future we can count on much of what is new being understandable to us. At the same time, using the apt definition of the noted mathematician K. Zinan, assessments and predictions of this type should be regarded as kind of "fantasy for scientists."

Following these introductory remarks we shall now consider the stochastic models of the evolution of cosmic civilizations based on these ideas.

1. Post-technological evolution. Let us recall the basic hypotheses of the stochastic approach to the evolution of cosmic civilizations formulated above. According to this hypothesis, Table 1 can be extended by adding several additional higher levels that differ qualitatively from each other. The transitions between these higher levels constitute the process of post-technological evolution. Clearly we have the right to extend the general laws of technoevolution to this process.

And even though we are unable at the present time to describe the contents of these new levels of development in detail, this approach still enables us to point out some of the shared features of evolution. One of the consequences of this approach is that the duration of the technoevolution of cosmic civilizations as compared to that estimated earlier (10^3 - 10^5 years) is at least several times as long, but remains as before substantially less than the age of the Metagalaxy.

2. Paradoxical evolution. This model is based on some paradoxical physical hypotheses put forward recently by theoretical scientists, but not yet verified experimentally. Let us consider some examples of such hypotheses that may be used as the basis for highly unusual versions of the evolution of cosmic civilizations. /38

We begin with the hypothesis of Academician M. A. Markov about the macro-micrometric Universe. According to the General Theory of Relativity, if the mass of a system is sufficiently great, then, starting from some value of the radius of this system, the larger the radius grows, the smaller the area of its surface becomes. This surprising property, of course, differs sharply from the usual results obtained from Euclidean geometry. Nevertheless, it must be accepted as true, because it is derived from the General Theory of Relativity, which has been verified by a large number of experiments.

Let us continue. If the mass within a sphere is very great, then in the limit that such a system contains the entire Metagalaxy, the sphere disappears to an outside observer. M. A. Markov showed that when some additional assumptions are made, the system proves to be incompletely closed: it will appear to external observers as a microparticle with a mass on the order of 10^{-6} g and a diameter of 10^{-33} cm. Objects of this kind, that may contain within them an entire Metagalaxy, but appear to the external world as elementary particles, Markov proposed calling fridmons, in honor of the noted Soviet scientist A. A. Fridman.

Do the fridmons that arose at the tip of the pen of the theoretical scientist exist in fact? As yet, we do not know.

But we do have the right to attempt to answer the second question: if these hypothetical particles, each of which can contain within itself an entire Metagalaxy with unknown properties, are real, how would that affect our concepts concerning the evolution of cosmic civilizations? From this point of view we cannot exclude the possibility that our own Metagalaxy is also such a fridmon, and in the world surrounding us there may in turn exist other fridmons, which to the terrestrial observer will appear as elementary particles. This reminds us of the famous verse of V. Bryusov:

And what if electrons are whirling worlds,
With continents and seas,
With art, and science, wars, and thrones, /39
And a history of forty centuries!

Considering the possible consequences of Markov's hypothesis for the evolution of cosmic civilizations, it is possible to point out a number of fundamentally new possibilities for creation and transformation by these civilizations: the establishment of relations with another Metagalaxy through the microscopic opening of the fridmon, etc. Furthermore, since the objects of the microworld are accessible to direct influence via high-energy elementary particle accelerators, there is in principle the possibility of actively influencing the structure of the Metagalaxy within the fridmon. However, such a possibility belongs more properly to the following model of the stochastic evolution of cosmic civilizations.

In addition to the hypothesis of M. A. Markov about the macro-microsymmetry of the Universe, it is possible to point out a whole series of other surprising consequences of the General Theory of Relativity that are interesting for analyzing the paradoxical evolution of cosmic civilizations: black and white holes, the simultaneous existence of Metagalaxies with different physical properties, space with variable metrics, etc. There is no possibility here of examining these consequences in any kind of detail, and besides, the majority of these predictions based on the theory have not yet been tested experimentally. We shall confine ourselves to a single example of how similar hypothetical phenomena or properties of the Universe can influence the evolution of cosmic civilizations. This example is from N. S. Kardashev who proposed the hypothesis that civilizations capable of completing journeys to other Metagalaxies using the unusual properties of the space-time continuum in the neighborhood of black holes are surprising cosmic objects predicted by the General Theory of Relativity.

3. Cosmocreatics. This model of evolution implies the hypothetical activity of an intelligence directed toward the fundamental reconfiguration of the structure of the material world, including, perhaps, changing its space-time properties and some of its fundamental laws. One such example has already been given above in connection with the analysis of Markov's fridmon hypothesis.

Various versions of this model of evolution are considered by S. Lem in his book Summa Technologia ("producing new information by computer," "cosmogonic construction--the creation of new worlds," etc.). Defining this problem concretely, N. S. Kardashev even raised the question of whether the expansion of the observable part of the Universe may not be the result of the activity of some super-civilization. /40

It would, however, be a fundamental error to regard this model of evolution as a realization of Kant's thesis of idealization: reason dictates its own laws to nature. But this is an entirely different matter, the utilization of more general principles and laws, acting on the material world, to govern various specific processes of a more particular nature in the interests of the civilization.

4. Autoevolution of intelligent life. If a cosmic intelligence finds it useful for its purposes to reconstruct some of the fundamental properties of its world (cosmocreatics), then it may set itself the goal of restructuring itself. In fact, one such example has already been considered above, namely, the transition to the state of the noobiont. Another example, heteronomous evolution, is considered in the next chapter.

An important characteristic of the three last models of metascientific evolution is that the duration of the developmental phases of a civilization may be quite significant. This is even more valid for such models as those of paradoxical evolution or cosmocreatics, when the very passage of time may be highly nonuniform. What, for example, is the "time" of a fridmon and the "time" of an experimenter external to its system?

HETERONOMOUS EVOLUTION

Is heteronomous evolution inevitable? "Heteros" in Greek means "other, different." Heteronomous evolution, in contrast to the autonomous evolution of a single civilization, means the simultaneous evolution of a number of interacting cosmic civilizations.

There is a fairly widely spead view that the biological species Homo sapiens or something similar to it is the acme of intelligent life. Having reached this peak, evolution will cease, and further changes are simply impossible. However, this /41
point of view is based on a misunderstanding. Even though intelligence itself is the highest point of development of matter, this says nothing about any particular shape in which intelligent life can exist anywhere in the Universe, including the form in which this life arose on our planet.

Here we should turn our attention to one more factor. The origin of intelligent life on Earth is a predictable result of evolution, but the selection of precisely the species Homo sapiens was due to chance. Thus, the origin of some specific form of intelligent life is a manifestation of the dialectical unity of the necessary and the accidental. Under different conditions, intelligence might be embodied by entirely different living beings, including beings having a different biology.

Let us recall one more dialectical law of the development of nature and thought, the law of the negation of the negation. According to this law, development proceeds via a sequence of cycles, each of which contains specific internal contradictions, which are the source of development and which ultimately make the transition to the next level of development inevitable, whereupon these contradictions disappear. This law reflects the continuation of the development of nature and thought, its negation as the replacement of the lower by the higher, the old by the new, but with the retention at the higher level of all the positive features characteristic of the lower level.

Taking the foregoing into consideration, let us return to the description given earlier of the highest state of intelligent life within the framework of the model of technoevolution, the noobiont. We discussed the dialectical unity of two mutually contradictory processes, the greatest possible development of the creative potential of the personality and the dissolution of the barriers between this personality and the collective intellect of the civilization as a whole. It was noted earlier that this internally contradictory process leads first of all to the greatest possible strengthening of the collective intellect of the cosmic civilization, and consequently, to the substantial growth in its basic transforming function.

But this same process, the gradual dissolution of interpersonal boundaries, has negative consequences, since taken /42
to the limit it can mean the excessive unification of intelligent life, a decline in its potential creative diversity, and consequently, a lowering of the creative ability of the civilization.

Intelligent life itself can be regarded as a breakdown in the symmetry of the Universe, since in the course of its evolution there is a thoroughgoing separation of living from nonliving, intelligent from nonintelligent. Violations of symmetry play an important role in the evolution of the Universe, since every time this happens there arise new states that differ from each other. But it is precisely in these successive transitions between qualitatively different states, apparently, that the evolution of intelligent life consists.

Thus, we arrive at the conclusion that the sequential development of contradictory processes that first leads to the transition of intelligent life to a higher level of evolution, to the state of the noobiont, ultimately forces it to face the danger of degeneration and a severely restricted potential diversity of its internal states. And one of the effective ways of eliminating or resolving this dialectical contradiction may be just this transition of the cosmic civilization to heteronomous evolution.

METACIVILIZATION. A practical expression of heteronomous evolution is the appearance of unions of civilizations, or

metacivilizations. Hypotheses about their emergence have been proposed before (The Great Ring [Velikoe kol'tso], by I. A. Yefremov and The Galactic Club [Galakticheskiy Klub] by R. Breisuelle), but in these works the major emphasis was on the problem of establishing contact. In contrast, for the model of heteronomous evolution the study of the structural and dynamic patterns of the development of civilizations are especially important. What is most important here is that the emergence of metacivilization in itself can be regarded as a necessary and predictable stage in the evolution of cosmic intelligence.

We can point out some preliminary conditions whose existence would makes the emergence of metacivilization appear entirely realistic.

1. There exist regions in the Universe with a sufficiently high density of cosmic civilizations at a level where they are capable of communicating.

2. The physical preconditions exist for establishing effective channels of communication. /43

3. There exists information guaranteeing that interaction with the alien intelligent life form does not involve any potentially serious dangers.

The following classification based on the means used to exchange information among the cosmic civilizations can be proposed for the models of metacivilizations:

1. The orthodox model of metacivilizations, based on the use of such now well-studied means of communication as radiocommunications, unmanned probes, etc. The obvious precondition for this model is that the density of civilizations in the given region of the Universe be sufficiently high.

2. The paradoxical model of metacivilizations, based on the hypothetical possibility of using some kind of fundamentally new phenomenon, such as the extremal properties of space-time, as a means of communication.

3. Metacivilizations of artificial origin.

Let us consider some of the general characteristics of each of these models. For the orthodox model, given a reasonable value of the average increment of evolution and the average density of cosmic civilizations, the order of magnitude of the number of civilizations comprising the metacivilization can be estimated. When radio communication is used as the means of information exchange such estimates give a number on the order of 10^3 for the average number of civilizations. Of course, these estimates are arbitrary, and the number cited should be viewed as only a rough guide.

For the orthodox model it is important to determine whether there exist anywhere in the Universe regions where the first of the preconditions set forth above is met for the emergence of metacivilizations. Unfortunately, the region of the Galaxy in which our solar system is found has been shown by the SETI research program not to be one of these.

Much more interesting in this respect is the core of the galaxy, where the density of stars is 2×10^4 times greater than that in the region of the Sun. In estimating the probability of the emergence of a metacivilization in the core of the galaxy it is essential to take into consideration the fact that in many galaxies these are regions where violent non-steady-state processes are occurring that are accompanied by the generation of vast amounts energy and penetrating hard radiation. On the other hand, intelligent life may arise under /44
such conditions, for example, under the protective cover of dense oceans at the surface or even below the surface of the planet, or even on the basis of a different biology, for example in the form of "macronuclear" life on the surface of neutron stars.

It may occur to the attentive reader to ask at this point how the heteronomous evolution leading to the emergence of metacivilizations differs from the unlimited conquest of new regions in space, the probability of which, as was seen earlier, is very small.

A difference does exist, and it is of fundamental importance. The extensive evolution of cosmic civilizations is chiefly the simple increase in spatial scale of the civilization to an unlimited extent. The idea of heteroevolution involves a transition to a qualitatively new stage of intelligent life.

Establishing contact among cosmic civilizations in the orthodox model is technologically a highly complex problem. According to estimates made by V. S. Troitskiy, the power of an omnidirectional radiobeacon that a civilization could use to establish initial contact over distances up to 1,000 lightyears would have to be 10^{18} Watts, and its mass 5×10^{19} tons, i.e. about 0.2 % of the mass of the Earth [4]. Because of ecological considerations, such a radiobeacon would have to be situated beyond the boundaries of the Solar System, so that at least 5×10^{19} tons of nuclear fuel would have to be expended on transporting its component parts. Because of the same considerations, the time required for its construction would be no less than 30 million years.

Under these conditions, an autonomous civilization whose internal dialectic of development faces it with the necessity of moving to this stage must turn to the third model, i. e. to /45
the artificial creation of "partners" in heteronomous evolution.

Practical ways of solving this super-task of cosmic civilizations may differ. In some version this may involve the "panspermia" hypothesis proposed by Francis Crick and L. Orgel to explain the emergence of life on our planet with its universal genetic code.

Other ways of inducing heteronomous evolution are also possible. It is possible to consider a completely staged contact, where the role of the other cosmic civilizations is played by a special set of programs installed in a computer of sufficiently great memory. So that the necessary randomness is allowed for (fundamentally new effects, unexpected discoveries, etc.) a special block to accomplish this function can be written in. The advantage of this method is that it allows many features of a real contact to be studied theoretically.

PATTERNS OF HETEROEVOLUTION. Let us now consider some general features of the process of heteroevolution that do not depend on the model chosen. Since the prime objective of the transition to the stage of a metacivilization is to raise the level of the effectiveness of the creative activity of the mind, it is appropriate to introduce a quantitative measure of such an increase in effectiveness. One such measure is the relative increase in the evolution increment or the value of the energy expended by the cosmic civilization on obtaining a unit of the information needed to maintain homeostasis and to expand its limits.

An obvious consequence of the emergence of a metacivilization will be the increase in the value of this effectiveness. The improvement in effectiveness is due to the division of labor, and to maintain the channels it is necessary to expend certain amounts of energy. However, the improvement in effectiveness achieved as the number of autonomous civilizations forming the metacivilization rises follows one mathematical law, and the corresponding rise in energy cost follows another. An idea of the colossal expense of cosmic communications among civilizations can be obtained from the estimates for the energy consumption of a radiobeacon computed by V. S. Troitskiy. /46

If we make a realistic assumption about the nonuniformity of the distribution of autonomous civilizations in space, assuming, for example, that their density is greatest close to some center and falls off with distance from it, then it can be shown that there exists some critical number of civilizations in the metacivilization, and when this number is exceeded, effectiveness declines instead of increasing as more civilizations are added.

Taking this result into consideration we can assume that the optimal strategy for a metacivilization must be to maintain its numbers at a level sufficiently far from this condition of instability. A second possible variant of the optimal strategy for a metacivilization is a programmed control of the number of

cosmic civilizations and the construction of artificial noosystems in qualitatively new hierarchial states. The creation of reserve noo- and biosystems (recalling the hypothesis of F. Crick and L. Orgel) is also a possibility. This variant of the strategy allows for the possibility that the optimum number of civilizations may change with a change in existing conditions and communications technology.

These consideration also allow us to conclude that if conditions suitable for the emergence of metacivilizations exist anywhere in the Universe, their actual structure may be fairly complex. In particular, different cosmic civilizations may possess different degrees of connectedness with one another. It can therefore be expected that there exist in the Universe still higher hierarchical informational structures, unions of metacivilizations.

There is still one more important consequence of the appearance of metacivilizations for intelligent life, the significant lengthening of the lifetime of the system. L. N. Nikishin was the first to point this out: since a metacivilization has in principle an open structure, then even if its members change for some reason, the overall period of existence of the whole and consequently is effectiveness is much increased.

The individual features of metacivilizations may prove to be quite specific in the case of the paradoxical model. In this case the requirement of a sufficiently high density of cosmic civilization and effectiveness of such traditional means of communication as radiocommunications prove not to be necessary. Moreover, if contacts among different bases of intelligent life are established on the basis of concepts about the macro-microsymmetry of the Universe, then realistic time scales for interacting civilizations may prove to be highly different. A quite feasible situation would be that a billion years for one system would be the equivalent of a much shorter time for another, down to fractions of a second. And this opens up new, surprising opportunities for the creative activity of the mind. /47

Even more expansive prospects for cooperation among the member cosmic civilizations may open up, if they turn to the paradoxical properties of the space-time continuum in the neighborhood of a black hole. In an analysis of the equation of the General Theory of Relativity by R. Kerr, I. D.Novikov, R. Penrose, S. Hawking, U. Kaufman and other researchers we note that under certain conditions the observer in the neighborhood of a black hole has the possibility of visiting a multitude of other worlds with different structural and physical properties, including, perhaps, its own metagalaxy in the past and in the future. In the last case we are actually talking about travel in time.

It would be premature to reject this last possibility on the grounds that it somehow contradicts the principle of causality. This is because under these condition the real structure of the space-time continuum may prove to be highly complex. In particular, if time-lines are closed, then events occurring along such lines are self-consistent and, consequently, the principle is not violated. In other words, all events occurring along a closed time-line influence each other.

ARE THERE ALIENS AMONG US? There are people who claim that aliens from other planets have often visited Earth in the past and continue to do so today in their UFO's, or "unidentified flying objects." "Scientific" disciplines have come into being to study these problems: "paleoastronautics" and "UFOlogy." After the notorious books and films of von Däniken and others of that ilk one would frankly prefer to avoid the subject. But on the other hand, the unhealthy excitement surrounding past and current "visits," the exaggerated rumors, cause no little harm to the serious study of the problem of cosmic intelligence. Furthermore, the flood of such publications is not slackening. For these reasons the author thought including this section in the book was warranted. /48

Take, for example, the booklet "Mysteries of the Star Islands" published in the USSR in 1982. On page 186 one can read the "uncanny and intriguing" story about the death of a little alien boy who had neither ears nor nose, and whose eye holes were situated on the sides of his head. His ship had an accident over the United States. Further on we learn that the details of this mysterious tale are hidden away in the archives of U.S. military intelligence.

What can you say about such publications? That they are just the ordinary speculations based unfounded rumors? But this wasn't enough for the compilers. On page 154 the following proposition is presented: the Moon is not a natural satellite of the Earth at all, but the mysterious Phaeton, a planet that formerly was located between Mars and Jupiter. Aliens moved this planet to its present orbit to leave us Earthlings something to remember their visit by. The proof? Well, actually, there is none, but on the other hand, how effective cheap sensationalism is.

We note only one more circumstance: on the pages of the same collection are included substantial articles by K. Feoktistov and other cosmonauts, and by serious engineers as well. Worst of all, these frivolous publications, based on unsubstantiated rumors or unproven speculation, and all mixed up with serious articles, may be taken on faith by the wide reading public.

It would be possible to present other examples, but "Mysteries of the Star Islands" is typical in this respect. The chase after cheap sensationalism, the credulous approach to the material, the lack of respect for serious science--this is the basis for all kinds of nonsense such as stories about little green

men who travel to our planet in their flying saucers in order to chat with the first passerby they encounter.

The actual state of affairs is entirely different. According to data from the Academy of Sciences of the USSR, more than 90% /49
of the reports of UFOs are due to uncommon natural phenomena or to the technological activity of humans. The remaining fraction of anomolous phenomena observed are not identified, chiefly because of insufficiently complete information provided by the observer. In the Soviet Union and abroad intensive scientific research is being conducted on these anomolous phenomena and a number of hypothesis have been proposed to account for their possible origin. What is most important here is to work on the basis of strict scientific principles.

It is somewhat different where it is a matter of information about visits to the Earth by aliens in the distant past. An example would be information about legends of the African tribe of the Dogons (Tekhnika Molodezhi, 1978, No. 1; 1981, No. 7; 1985, No. 1). According to these legends, as transcribed by French scientists, the Dogons know from visitors that Sirius is a binary star, they know the period of rotation of the satellite of Sirius C, its luminosity, its density, orbital perturbations, and even of the existence of yet another satellite of this star. This last is especially exciting: there is a possibility of testing the legend, since this satellite has not yet been discovered.

But let us think about something different: what meaning did the ancestors of the Dogons give to such terms as "satellite," "orbit," "luminosity," etc.? Where is the guarantee that all these terms have any kind of meaningful equivalents in the Dogon language?

The fundamental nature of these questions can be tested by turning to reports of a civilization about whose existence we have reliable evidence, the reports about the ancient civilization of Greece. The scientists of antiquity also wrote about the stars and planets. Here is what Plato wrote about the stars: these are "deities, with a body and a soul; their visible form consists basically of fire so that they appear as bright and beautiful as possible, and to resemble the Almighty they are made in the shape of a sphere. What does that have in common with what we understand by the term "star" today? By the way, this quotation is from Timaeus, which also includes the famous legend of Atlantis. And don't we have, based on this, reason to suppose that the ancient Egyptian priests from whom Plato learned about Atlantis were also talking about intelligent life on distant stars, /50
and that Plato wrote down these legends without completely understanding what they were all about? In any event, this would be a logical construction, no worse than anything else in "paleoastronautics."

Apparently it was not just by chance that one of the serious investigators of the problems of "paleoastronautics," S. I.

Lisevich, who studied some strange information contained in ancient Chinese texts dedicated to the emperor Huandi, came to the cautious conclusion that his task was to "give the reader something to think about."

And the last point. Analyzing the bountiful information on "UFOology" and "paleoastronautics" allows us to come to a brief and unambiguous conclusion: at the present time there is not a single fact that reliably testifies to visits by ambassadors from other cosmic civilizations to Earth, either in the past or the present. But the absence of proof is not proof of its absence. It is therefore logical to ask one more question: what is the probability of such visits in the light of the models of the evolution of cosmic civilizations we have considered? Taking into consideration the estimates of the effectiveness of contact and the different strategies for establishing it made on the basis of these models, it is possible to give an unambiguous answer: the probability of such visits is negligibly small.

INTELLIGENCE AND THE UNIVERSE

A METAMODEL OF THE EVOLUTION OF INTELLIGENT LIFE. The totality of the models of cosmic civilizations considered in the previous chapters can be represented single super-model, convenient for analyzing the probable paths of evolution. Such an approach makes it possible to account for the combination of the accidental and the necessary in the evolutionary process, and to consider the process itself in the light of different mutually complementary aspects of the problem.

The overall scheme of the models of the evolution of cosmic civilizations considered in this book is shown in Fig. 4. This single model should be understood as the totality of all possible paths of development of cosmic civilizations, it being impossible to determine unambiguously in advance to what degree these concepts correspond to reality. However, one can attempt to obtain an answer to another question: what is the probability density of the distribution of cosmic civilizations according to the particular models of their evolution? /51

To answer this question we shall start from the fundamental properties of life in general and of intelligent life in particular: since the basic function of life is to violate symmetry and to construct new levels of diversity, this probability density can be considered as being proportional to the number of such levels. Estimating the possible number of different levels within the framework of the different models of evolution of cosmic civilizations, it is therefore possible to construct a function of the possible distribution of cosmic civilizations on the basis of these models (the curve P in Fig. 5). In spite of the arbitrariness of the estimates, it is evident that the maximum probability occurs for heteronomous evolution.

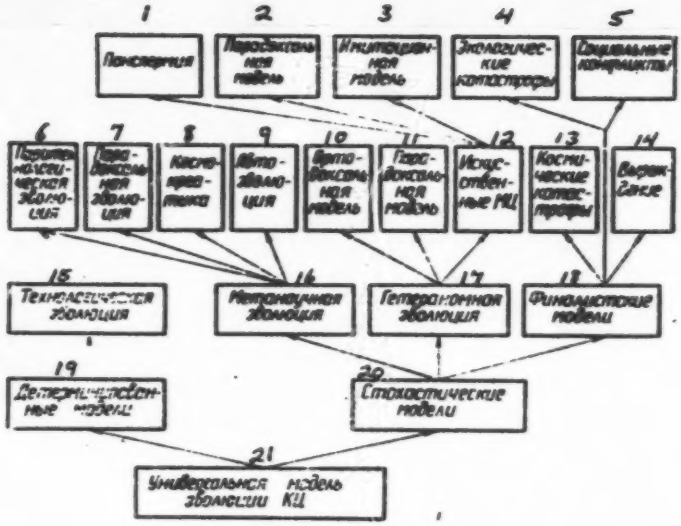

Fig. 4. Universal model of the evolution of cosmic civilizations (general scheme). Key: 1) Panspermia; 2) Paradoxical model; 3) Imitational model; 4) Ecological catastrophes; 5) Social conflicts; 6) Paratechnological evolution; 7) Paradoxical evolution; 8) Cosmocreatics; 9) Autonomous evolution; 10) Orthodox model; 11) Paradoxical model; 12) Artificial metacivilization; 13) Cosmic catastrophes; 14) Degeneration; 15) Technological evolution; 16) Metnscientific evolution; 17) Heteronomous evolution; 18) Finalistic models; 19) Deterministic models; 20) Stochastic models; 21) Universal model of the evolution of cosmic civilizations.

At this point it is essential to make an important observation. In one of the articles dealing with the possible development of physics, Academician V. L. Ginzburg introduced the concept of the "mathematical expectation" of solving some new physics problem, denoted by B. The value of B is equal to the derivative of the probability of solving the problem with respect to its theoretical and practical importance. No doubt, the fundamentally new discoveries referred to in the analyses of the metascientific models of evolution are more interesting in this regard. This prediction is taken into account in Fig. 5, where curve B illustrates this conclusion qualitatively. /52

Is there any possibility of considering, if only to a first approximation, the models of technoevolution and the stochastic models within the framework of a single temporal sequence? It is only at first glance that the process of technoevolution appears to be predetermined: new, unexpected discoveries, if they are made, will make it necessary to introduce substantial changes in the corresponding model. Nevertheless, there are grounds for an affirmative answer to the question posed. The "energy cost" of fundamental discoveries leading to radical

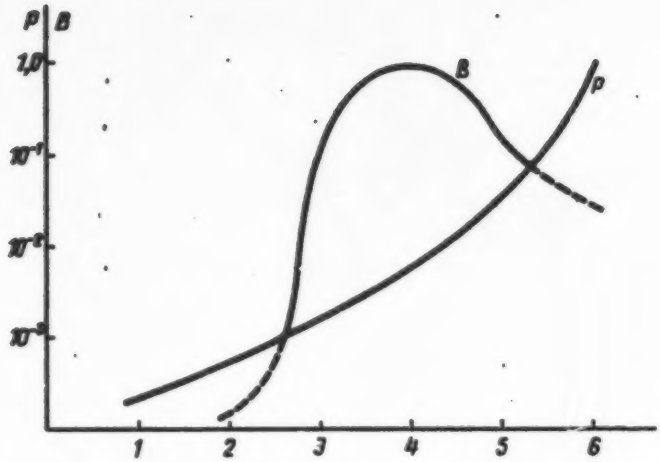

Fig. 5. Probability density P and "mathematical expectation" B for evolutionary models (horizontal coordinate values: 1) Destruction; 2) Civilization of pleasure; 3) Autonomous evolution of intelligent life; 4) Metascientific evolution; 5) Cosmocreatics; 6) Heteronomous evolution).

restructurings of the entire system of science has grown considerably in our day. The last radical restructuring of natural science was the formulation of quantum physics and the theory of relativity more than half a century ago. Considering the pace of technological evolution, it can be expected that at least in its initial stages further radical restructurings of the foundations of science will not occur. The temporal sequence of the stages in the evolution of cosmic civilizations corresponding to this is shown in Fig. 5. /53

NOOCOSMOLOGY. A revolutionary and fundamental role in the the formulation of modern scientific ideas about intelligent life in the Universe was played by the "antianthropocentric principle" of Copernicus and Giordano Bruno. In our day, after the beginning of active research on conquering the reaches of space, this principle led to the concept of radio civilizations capable of producing sufficient power to maintain contact with each other over cosmic distances. /54

This concept made it possible to avoid going too deeply into the complex problem of the patterns and evolutionary paths of cosmic civilizations, since the result of the searches depended little on the particular assumptions of the model. Unfortunately, this idea has as yet not proved fruitful: the search for radio signals or "cosmic oddities" of artificial origin has produced nothing.

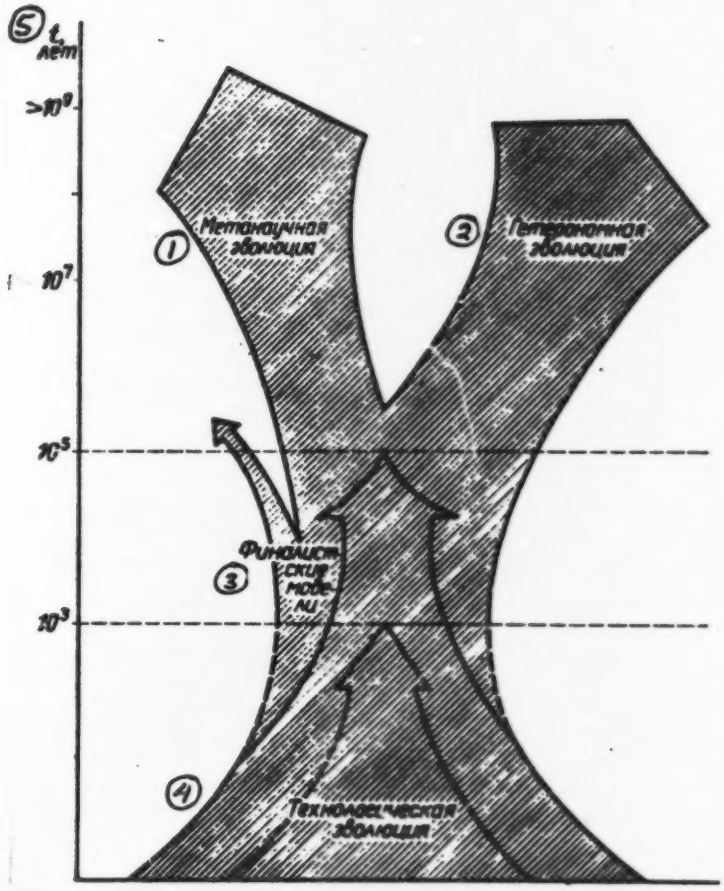

Fig. 6. Dynamics of the evolution of cosmic civilizations within the framework of a universal model. Key: 1) Metascientific evolution; 2) Heteronomous evolution; 3) Finalistic models; 4) Technological evolution; 5) years.

The most probable reason for this lack of success at the first stage of the search lies in the shortcomings of the instrumentation used, the insufficient sensitivity of the receivers, and the insufficiently broad scope of the search. It is therefore premature to conclude that we are alone in the Universe on the basis of this failure.

Further advances in research on SETI urgently require expanding and refining our fundamental ideas about the role and place of intelligent life in the Universe, and about the behavior patterns and evolutionary paths of cosmic civilizations. To make the search more specific it is essential to have a better understanding of whom we are seeking. Research on these question will, it appears, become the object of a new scientific discipline, noocosmology, i.e., the study of intelligent life in the Universe.

The major conclusion to be drawn from the models considered is that the actual structure of the cosmic noosphere may prove to be highly complex. To what extent these ideas correspondond to reality can be determined only by direct experimentation.

In planning research at the next stage of SETI the following desires can be expressed:

1. The experiments within the framework of the program to search for radio signals from other cosmic civilizations should not be curtailed, since these are the most accessible at the present time. These investigations are still at the inital stage, /55
and obtaining negative results will have no less conceptual significance than a successful search.

2. The research program should have a more integrated and multidisciplinary character, and research based on using different approaches should be incorporated.

3. The systematic analysis of the problems of the evolution of cosmic civilizations will become useful even in the case that further research confirms the hypothesis that we are essentially alone in the Universe. Systematic concepts about the evolutionary paths and behavior patterns of cosmic civilizations can be regarded as an evaluation of the prospects for the advancement of our own civilization over quite considerable expanses of time.

NOTES

1. World Energy. Predictions of Development to the Year 2020. [Mirovaya energetika. Prognoz razvitiya do 2020] ch., "Energiya" Press, Moscow (1980).

2. N. N. Semonov, Science and Society [Nauka i obshchestvo], Nauka, Moscow (1983), pp. 109-144.

3. N. P. Dubini (editor), General Biology, [Obshchaya biologiya], Prosveshchenie, Moscow (1980).

4. V. S. Troitskiy, "The development of extraterrestrial civilizations and physical patterns," in The Search for Extraterrestrial Civilizations [Problema poiska vnezemnykh tsivilizatiy], Nauka, Moscow (1981), pp. 5-28.

REFERENCES

Goldsmith, D. and T. Owen, The Search for Life in the Universe [Russian translation], Mir, Moscow, 1983.

Komarov, V. N. and B. N. Panovkin, Homo Sapiens [Chelovek poznayushchiy], Moscovskiy Rabochiy, Moscow, 1983.

Konstantinov, B. P. (editor), The Inhabited Cosmos [Naselennyi kosmos], Nauka, Moscow, 1972.

Lem, S., Summa Technologia [Russian translation], Mir, Moscow, 1968.

Mukhin, L. M. The Planets and Life [Planety i zhizn'], Molodaya Gvardiya, Moscow, 1984.

Shklovskiy, I. S., The Universe, Life, and Intelligence [Vselennaya, zhizn', razum], Nauka, Moscow, 1980.

Shkolenko, Yu. A., Philosophy, Ecology, and Astronautics [Filosofiya, ekologiya, kosmonavtika], Mysl', Moscow, 1983.

Troitskiy, V. S. and N. S. Kardashev (editors), The Search for Extraterrestrial Civilizations [Problema poiska vnezemnykh tsivilizatsiy], Nauka, Moscow, 1981.

Ulubekov, A. T. The Wealth of Extraterrestrial Resources [Bogatstva vnezemnykh resursov], Znanie, Moscow, 1984.